Dear Editor and Reviewer;

We thank you for your review and comments; It is a merriment that the reviewer don't has objections on the method developed to quantify the different hydraulic head of de several stretches existing in a well, and on the proposal to minimize a problem so critical as the arsenic content of the water supply of Madrid city. We attach the response indicating the changes we have made. We are confident that we have given a satisfactory response to all comments.

In the responses the reviewer comments in pdf are referring to lines (L) of the fourth version of the manuscript, and the modifications and explanations are referring to lines of fifth version of the manuscript. A document has been attached (fifth version) in which the proposed changes are differentiated in red text.

Responses to the reviewer comments

General comments

- Introduction is hard to follow: phrases are sometimes too long, while the link in between different paragraphs is missing.

Following the reviewer's recommendations, several modifications have been made to the introduction and some sentences have been shortened. These changes are already reflected in the responses to the specific comments.

- The methodology section, especially section 2.3, also needs some clarifications, as the current description is very unclear (both in terms of the grammar and the physics).

We believe that the answers to the specific comments corresponding to background section 2.3 already respond to this comment.

- Section 3 does not really add the clarity to this work, as the authors always reference to some hypothetical cases without really proposing the experimental design. Or, simply, do you stick to some particular field site from the beginning? Do we deal with porous media (as in figure 3) or with fractured media (as in Paillet, 1998); cross-hole or single-hole?

The text until section 4, of Case Study, in which the experimental characteristics of the study are presented, focuses in a general analysis of spinner flowmeter logging and step-drawdown pumping test.

We would like to point out that, although in the introduction section already appeared cites to "continental detrital basins" and "multilayer detrital aquifer", the text on fractured media were added to take into account the previous reviews by Paillet on the manuscript.

We believe that the answers to the specific comments corresponding to section 3 already respond to these general comments.

Specific comments on pdf

1. Comment "this is questionable, as lithology knowledge is local and not necessarily representative of the hole aquifer", in L26-L28 refers to the text:

"One of the most interesting hydrogeological aspects of well pumping tests is that their results not only allow to estimate the permeability and transmissivity obtained in the well but can also be used to infer the behaviour of the aquifer when the lithological distribution of the basin in its location is known."

Indeed, the different lithological layers traversed by a borehole in a large continental detrital basin do not necessarily correlate with those of another borehole at a certain distance. However, regarding to stretches (the units in which the manuscript is focused) they have a greater spatial extension; so, in new L95, it is said that:

"These stretches show some parallelism with zonation relative to the average grain sizes shown in Díaz-Curiel et al. (1995), which spatial extension is addressed in the discussion section".

Thus, the aquifer units (predominantly permeable) from 280 m reflected in Fig. 4, show as a whole a high degree of correlation up to distances of 10 km. These lithological units correspond to the stretches with the highest water input (highest permeability) determined by flowmeter logs.

Following the reviewer's comment, we have added in the new L28-L29:

"This estimate of basin behaviour will be less accurate when knowledge of the lithology is local."

2. Comment "the reader does not necessarily knows what does it mean.", in L34-L35 refers to the text:

   "non-linear behaviour coefficient that can be different for each step"

   We believe that with what is shown in new L485-L498 and L525-L530, the meaning attributed in this manuscript to this nonlinear coefficient is clearly presented.

   Following the reviewer's comment, we have modified the text in new L34-L37:

   "These models provide an accurate representation of the aquifer behaviour for any pumping time. Among other results, Mathias and Todman (2010) found that the best fit was achieved by using a non-linear behaviour coefficient that can be different for each step, obtaining its values by means of an analytical formula derived to relate this coefficient to the Forchheimer parameter."

   By:

   "These models provide an accurate representation of the aquifer behaviour for any pumping time. Among other results, Mathias and Todman (2010) found that the best fit was achieved by using a nonlinear coefficient, called "well loss coefficient", that can be different for each step. The values of this coefficient were obtained using an analytical formula derived to relate this coefficient to the Forchheimer parameter."

3. Comment "an explaination figure would be helpful. The reader is not supposed to check the results from the cited study to understand the present text.", in L36 refers to the text:

   "When the drawdown versus the extraction rate curve presents an increasing slope"

   Following the reviewer's comment, we have added a refer to the generic figure 1 in the manuscript, replacing in new L37-L39:

   "When the drawdown versus the extraction rate curve presents an increasing slope (as in the case of the step-drawdown test from Clark (1977)), there are different hydrogeological explanations.

   By:

   "When the drawdown versus the extraction rate curve presents an increasing slope, as in the case of the step-drawdown test from Clark (1977) (a similar behaviour can be seen in the generic curves 2 and 3 shown in Fig. 1), there are different hydrogeological explanations."

4. Comment "see my previous remark", in L39 refers to the text:

   "stages of the step-drawdown test from Van Tonder"

   Following the reviewer's comment, we have added a refer to the generic figure 1 in the manuscript, replacing in new L39-L42:

   "However, when the slope decreases and the specific capacity versus the drawdown increases, i.e., when the hydric behaviour improves with increasing flow rate (as in the last two stages of the step-drawdown test from Van Tonder et al., 2001), the only explanation …"

   By:

   "However, when the slope decreases and the specific capacity versus the drawdown increases, i.e., when the hydric behaviour improves with increasing flow rate, as in the last two stages of the step-drawdown test from Van Tonder et al., 2001 (a similar behaviour can be seen in the generic curve 4 shown in Fig. 1). The only explanation …"

5. Comment "ref are needed to justify", in L49-50 refers to the text:

   "A situation that is not often considered in studies on great continental basins that are hundreds of metres deep is that the diverse permeable layers crossed by water wells can have different hydraulic heads"

   We would like to point out the difficulty of presenting references of studies on well characteristics that have not been published before. In fact, in previous reviews by Paillet it is stated that this hydraulic difference in continental detrital basins is a novelty.

   Following the reviewer's comment, we have modified the above text (now in L51-L52) as follows:

   "A situation that is not often considered in studies on great continental detrital basins that are hundreds of metres deep is that the diverse permeable layers crossed by water wells can have different hydraulic heads"

6. Comment "This part is impossible to follow without reading works by Paillet.", in L62 refers to the text:

   "(4.54, 4.91, 4.91 and 4.91 m below ground level)"

   We would like to point out that the resume of the developments presented in various publications from Paillet, was included in the manuscript to reflect the differences between those developments and the method used in the manuscript.

   Following the comment of the reviewer, we have modified the text in new L69-L71:

   "… *be significant*", hydraulic head values (4.54, 4.91, 4.91 and 4.91 m below ground level) are presented for the four productive stretches in one of the boreholes analyzed, …"

   By:

   "…*be significant*". The hydraulic head values (4.54, 4.91, 4.91, 4.91 and 4.91 m below ground level) obtained for the four productive intervals found in one of the analyzed boreholes are also presented in that work, …"

7. Comment "I do not understand what is meant", in L82-83 refers to the text:

   "In this work, the term 'flow stretch' is primarily used for differentiate sets of screens that corresponding to more permeable units (aquifers) among which there are other stretches (aquitards) mainly corresponding to less permeable units"

   Following the reviewer's comment, we have modified the above text (now in L85-L87) as follows:

   "In this work, the term 'flow stretch' is primarily used for differentiate sets of consecutive screens located at depths of the more permeable units (aquifers) among which there are other stretches mainly corresponding to less permeable units (aquitards)"

8. Comment "This is the first time you explain the principle of the flowmeter testing. It should be done before/", in L96 refers to the text:

   "Regarding the hydraulic interpretation of flowmeter logs, its main advantage lies in the fact that different permeable layers that the well crosses may have different hydraulic properties."

   We have modified the order in which the ideas are presented, placing the part corresponding to the principle of the flowmeter testing immediately after the part corresponding to the pumping tests, now in L57-L61.

   We have moved to new L57, the text in L70:

   "Flowmeter logging is conventionally used to determine variations in the flow velocity along a well casing, allowing water inputs at different depths that contribute to the total discharge rate to be computed. These quantities are used to estimate changes in hydraulic characteristics with depth, thereby improving the management and rational exploitation of aquifers."

   Also, we have moved and modified to new L59, the text in L73:

"In addition to this conventional purpose, a process to provide information regarding different hydraulic heads in fractured rock media from flowmeter logs was proposed in several works by Paillet."

Also, in new L76-L79 we have modified:

"This communication presents the possibilities of the flowmeter log to provide a hydrogeological explanation of the described anomalous cases. Flowmeter logging is conventionally used to determine variations in the flow velocity along a well casing, 70 allowing water inputs at different depths that contribute to the total discharge rate to be computed. These quantities are used to estimate changes in hydraulic characteristics with depth, thereby improving the management and rational exploitation of aquifers. In addition to this conventional purpose, a method has been developed in this work that uses flowmeter logs to provide information regarding different hydraulic heads in a multilayer basin. Moreover, determining these different hydraulic heads allows hydraulic reinterpretation that explains the abovementioned anomalous behaviours of the pumping test results."

By:

"This communication presents the possibilities of the flowmeter log to provide a hydrogeological explanation of the described anomalous cases. With this aim, in this work a method has been developed that uses flowmeter logs to provide information regarding different hydraulic heads in a multilayer basin. Determining these different hydraulic heads allows hydraulic reinterpretation that explains the abovementioned anomalous behaviours of the pumping test results."

9. Comment "This is unclear", in L195-L196 refers to the text:

   "The need for an exhaustive treatment of the flowmeter logs arose initially to avoid doubts on observed anomalies in the characteristic curves of the step-drawdown test could stem from the reliability of the flowmeter log results."

   Following the reviewer's comment, we have modified the above text (now in L199-L201) by:

   "The need for an exhaustive treatment of the flowmeter logs arose initially to rule out that the anomalies observed in the characteristic curves of the step-drawdown pumping test could stem from the reliability of the flowmeter log results themselves."

10. Comment "precise what kind of effects do you mean", in L197 refers to the text:

    "Thus, it had to be shown that such effects…"

    Following the reviewer's comment, we have modified the above text (now in L201) by:

    "Thus, it had to be shown that such anomalies…"

11. Comment "not clear", in L204-205 refers to the text:

    "Then, a relationship τ(Re) that provides the flow turbulence exponent τ as a function of the Reynolds number is applied."

    We thought that L204-L220 resume for any reader related to hydrogeology, the main parameters of water flow in pipes and capillaries. Following the reviewer's recommendation, we have modified the above text by (now in L208-L209):

    "Then, the relationship τ(Re) given by Eq. (4) that provides the flow turbulence exponent τ as a function of the Reynolds number is applied."

12. Comment "This is very hard to follow and not clear. Better synthesis of the study by Diaz-Curiel et al. is required, in L212 refers to the text:

    "to obtain Re(z)"

    Following the reviewer's recommendation on the flow chart in Figure 2, in L204-L220 we have made the following changes:

    "This exhaustive process of the flowmeter logs will be done according to the laws of pipe hydraulics using the methodology developed by Díaz-Curiel et al. (2020). To obtain the flow velocity at each depth, $<V(z)>$, a conventional iterative process is used. It begins by taking the measured velocity V_{meas} at a given depth as the initial flow velocity and the initial Reynolds number Re_{ini} according to its definition, that is, Re= $\rho \cdot \langle V \rangle \cdot D/\mu$, where ρ is the water density, *D* the well diameter and μ the dynamic viscosity. Then, the relationship τ(Re) (see Eq. (4)) that provides the flow turbulence exponent τ as a function of the Reynolds number is applied.

$$\tau(\mathrm{Re}): \tau = \frac{(\mathrm{Re}/2490)^{9.994} + 1}{0.2 \cdot (\mathrm{Re}/2490)^{9.9} + 1} \qquad (4)$$

Knowing the turbulence exponent τ and the normalized radius r_D of the sonde (the ratio of the sonde distance to the well axis with respect to the well radius), a velocity law must be applied. This law is the ratio between the velocity at the normalized distance $V(r_D)$ and the maximum velocity in the well axis *V*max (see Eq. (5)); this allows this maximum value to be obtained.

$$V(r_D): \frac{V(r_\mathrm{D})}{V_{\max}} = \left(1 - r_\mathrm{D}{}^{\tau+2/\tau+0.5}\right)^{1/\tau} \qquad (5)$$

Then, using the relationship for the velocity factor $F_{vel}(\tau)$, defined as the ratio between *V*max and the flow velocity <*V*> (see Eq. (6)), the first flow velocity is obtained with the corresponding Reynolds number Re_{ini}, which is closer to the actual value.

$$\mathrm{F_{vel}}(\tau): \mathrm{F_{vel}} = \frac{\langle V \rangle}{V_{\max}} = \frac{\tau + 0.5}{\tau + 2} \qquad (6)$$

Applying τ(Re), $V(r_D)$, and $F_{vel}(\tau)$, a new Re value Re_k is obtained (k being the iteration index of the convergence algorithm). This process is repeated until a given convergence criterion c_{CR} (Re_k - Re_{k-1}> c_{CR}) is reached. The process schematic is summarized in the flow chart in Fig. 2 (adapted from Díaz-Curiel et al., 2020), to obtain Re(z)."

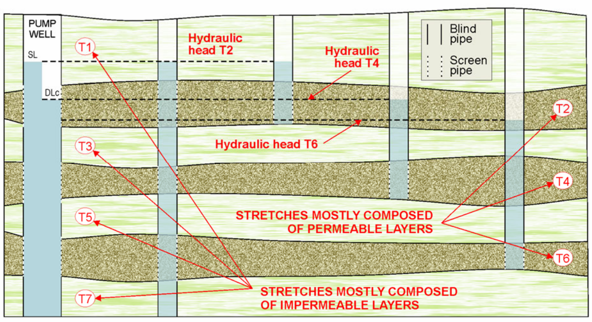
13. Comment "You should describe first the experimental conditions. Where do you pump? Where do you perform the flowmeter logs? what is dlc?", refers to Fig. 3.

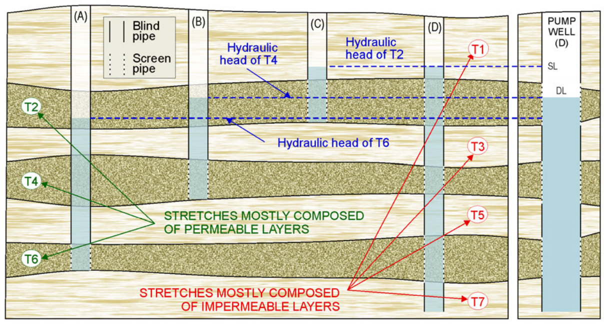
This is an example scheme to explain the existence of permeable stretches with different hydraulic heads. It is not a pumping done at any specific location. DLc is the "dynamic level" as indicated in the caption (renamed now to DL). To make the figure easier we have made the following modifications to the figure:

The names (A), (B), (C) and (D) have been added to the hypothetical wells.

The different "hydraulic head Tx" has been changed to "hydraulic head of Tx".

The old figure 3: has been replaced by:





Following the reviewer's comment, we have also modified the caption:

"Figure 3. Scheme of the resulting hydraulic head from the existence of permeable stretches with different hydraulic heads. With the plotted dynamic level DLc, only T2 contribute water to the well, T4 do not, and T6 collect water from the well."

By:

"Figure 3. Hypothetical example on the results that would be obtained in a large detrital basin composed of 7 different stretches so that: Permeable stretches T2, T4, and T6 would be hydraulically separated from each other by impermeable stretches T1, T3, T5, and T7; stretches T2, T4, and T6 would have different hydraulic heads, which are drawn in hypothetical wells A, B, C, and D, with different depths and different filtering intervals. Considering the plotted depth and filter intervals of well D, if pumped with the plotted dynamic level DL (coincident with hydraulic head of T4, see the right part of figure), only T2 stretch contributes water to the well, T4 does not, and T6 collects water from the well. Note that the well diameters plotted are not scaled, but highly magnified to enhance the view of the figure."

14. Comment "The same, the authors always reference to some hypothetical cases without really proposing the experimental design.", in L248 refers to the text:

    "In most flowmeter logging with several pumping steps"

    Following the comment of the reviewer, we have replaced:

    "In most flowmeter logging with several pumping steps, the drawdown used in the Thiem (1906) equation is the same for all of the aquifer stretches in a well, $d_0(s)= h_{DL}(s)-H_{SL}$ where $h_{DL}(s)$ is the dynamic level for the 's' pumping step and H_{SL} is the dynamic level of the entire well."

    By (now in L257-L261):

    "In most works on hydraulic interpretation of flowmeter logs a unique hydraulic head given by the static level H_{SL} of the entire well is considered (Molz et al., 1989; Rehfeldt et al., 1992; Ruud and Kabala, 1996; Zlotnik and Zurbuchen, 2003a; Barahona-Palomo, et al. 2011; Riva et al., 2012). Thus, the drawdown used in the Thiem (1906) equation is the same for all of the aquifer stretches in a well, $d_0(s)=h_{DL}(s)-H_{SL}$, where $h_{DL}(s)$ is the dynamic level for the 's' pumping step and H_{SL} is the dynamic level of the entire well."

15. Comment "Does it bring some advatages? What is the reason?", in L256-257 refers to the text:

    "The main differences with the method used by Paillet (1998) are that we have chosen to use the Rehfeldt relationship (Eq. 2) for permeability instead of the Davis and DeWeist relationship (1966) relation for transmissivity,…"

    Following the reviewer's recommendation, the reasons have been added to the above text (now in L267-L270):

    "The main differences with the method used by Paillet (1998) are that we have chosen to use the Rehfeldt relationship (Eq. 2) for permeability instead of the Davis and DeWiest relationship (1966) relation for transmissivity, given that the thickness of the layers and the productive sections are taken into account. The advantage of this option is that it is not necessary to know the storage coefficient of each contribution interval studied."

16. Comment "what do you mean?, in L265 refers to the text:

    "and although other local well factors"

    We refer to the local well factors described in new L166-170

17. Comment "precise?", in L293 refers to the text:

    "and conventional well logs"

    Following the comment of the reviewer, we have replaced:

    "A lithological column was compiled from information provided by the detritus from the borehole and conventional well logs; the normal resistivity and natural gamma ray records are presented in Fig. 4."

    By (now in L304-306):

    "A lithological column was compiled from information provided by the detritus from the borehole and conventional well logs: normal resistivity and natural gamma ray logs, which are presented in Fig. 4."

18. Comment "what type of flowmwtwer was used?", in L344 refers to the text:

    "flowmeter logging"

    Following the reviewer's comment, the type of used flowmeter has been added in new L360.

    "Since the flowmeter logs (spinner type) were collected during pumping operations,…"

19. Comment "would be useful to see the raw data? what is the sampling rate ?", refers to Fig. 7.

The raw data is available in Mendeley, the link is provided on the Hess web page in the "assets for review".

The sampling rate is a function of the sonde velocity, as internally analogically measures the spinner rotation providing the average values over a 2 s window. Since to use the calibration curves it is necessary logging at 3 different velocities, the mean value of the "sampling rate" was 33 cm.

We have added this information in the new L363-L364:

"The logs were obtained with an average sampling rate of 33 cm. Once calibration has been applied, the velocity obtained is averaged from the top of each screen to the bottom of the next, obtaining the values at 40 depths that appear in the raw data"